Astro 596/496 PC
Lecture 2
Jan 22, 2010

Announcements:

- Preflight 1 due Fri. Jan 29, 12noon

Last time: Overview
at the *Univers*ity of Illinois we promise the whole cosmos
...it's right there in the name!
in this course: we deliver!

Today's Agenda: The great work begins! Dive in!

⋆ cosmologist's observational toolbox
⋆ zeroth-order structure, kinematics of the Universe

Program Notes: ASTR596/496PC Bugs/Features

- notes online–but come to class!
  some people find it convenient to print 4 pages/sheet
- class $\in$ diverse backgrounds: ask questions!
- Socratic questions
- typos/sign errors
  Dirac story
  please report errors in lectures and problem sets;
  email notifications sent out

Physical Cosmology

Modest goals:
scientific understanding of the

- origin
- evolution
- contents
- structure
- future

of the Universe

To be a science: must have empirical evidence
$\longrightarrow$ need observable data to reveal/test the above

Q: What are cosmological observables?
hint: there are a wide variety

Cosmological Observables

"Raw" – hot off the instrument

Local: Terrestrial/Solar System

- meteorites
- lunar samples
- solar wind

Nonlocal: "Heavenly Messengers"

- photon signals: individual objects
  local and Galactic: Sun, stars, gas
  extragalactic: galaxies, QSO, etc
- diffuse photon backgrounds (all λ: radio–gamma ray)
- cosmic rays
- neutrinos
- gravity waves
- dark matter particles (?)

"Cooked" – After Analysis

- meteorite, solar wind, moonrock composition
  elements, isotopes
- photon spectra of stars, galaxies, interstellar/intergalactic gas
  $\rightarrow$ element composition, red/blueshifts, temperature
- galaxy distribution
- galaxy distortions (lensing)
- ...

Armed with these, we proceed...

Bizarre Astronomical Units I: Distances

Charity begins at home: *Astronomical Unit* (AU)

- average Earth-Sun distance, known very precisely
- $r(\text{Earth} - \odot) \equiv 1\ \text{AU} = 1.49597870660 \times 10^{13}\ \text{cm}$

parsec

- derives from trigonometric parallax measures of stars
- star with parallactic angle p lies at distance

$$r(p) = \frac{1\ \text{AU}}{\tan p} \approx \frac{1\ \text{AU}}{p} \quad (1)$$

for $p = 1$ arcsec $= 4.8 \times 10^{-6}$ rad, distance is

$$r(1\ \text{arcsec}) \equiv 1\ \text{parsec} \equiv 1\ \text{pc} = 3.0857 \times 10^{18}\ \text{cm} \approx 3\ \text{lyr} \quad (2)$$

The Shape and Scale of the Universe

basic & ancient questions:
• how old is the universe?
• how big is the universe?
• what is the universe made of?
note: one's idea of "universe" implicitly presupposes aspects of answers to these questions

historically:
• dramatic upward revisions in scale of U
• drastic broadening in known cosmic composition

from Newton to early 20th Century:
$\Rightarrow$ *Universe* $\equiv$ *Milky Way*: a (finite) collection of *stars*
size $\sim$ kpc $= 10^3$ pc

The Realm of the Nebulae

hottest question in 1920's astronomy:
what are spiral "nebulae"?

`www: Mikly Way and Galactic coordinates`

`www: NGC sky and zone of avoidance`

tool: Cephieds–variable stars

`www: Cephieds then and now`

$\Rightarrow$ periodically changing **luminosity**

L = light **power** output = source "wattage"

calibrate locally, then apply to nebulae:
  from period $P \Rightarrow$ infer L

Measure: *photon energy flow* (power) dE/dt
onto *detector* of *area* dA
but clearly $dE/dt \propto dA$: depends on detector *Q: why?*
Q: how to remove detector dependence?

intrinsic to source and distance: energy **flux** (current density)

$$F = \frac{dE}{dA\,dt} = \frac{d\text{Power}}{d\text{Area}} = \frac{L}{4\pi R^2} \tag{3}$$

inverse square law
for Euclidean geometry, stationary source, isotropic emission

But if lucky or clever: L known (**“standard candle”**)
solve for “luminosity distance”

$$d_L = \sqrt{\frac{L}{4\pi F}} \tag{4}$$

Hubble: Cephieds in “Andromeda Nebula” M31
$d_L \sim 10^3$ kpc $\gg R_{\text{MilkyWay}}$
$\Rightarrow$ M31 is “island universe” = galaxy
cosmic distance scale grew by factor ~ 1000: kpc $\rightarrow$ Mpc

So to summarize:
Q: pc, kpc, Mpc, Gpc *characteristic scales for what?*

Typical Lengthscales: Cosmic Hierarchy

⋆ typical star-star separation in galaxies ~ 1 pc

⋆ typical (visible) galaxy size $\sim$ 1kpc $= 10^3$ pc

⋆ (present-day) typical galaxy-galaxy separation
~ 1 Mpc $= 10^6$ pc

⋆ (present-day) observable universe ~ 1 Gpc $= 10^9$ pc

Q: Why is this a "hierarchy"?

Observational Cosmology: Zeroth-Order Picture

Cosmic Matter Distribution

Q: how quantify distribution?

Q: how characterize smoothness/lumpiness?

Q: how determine observationally?

observable cosmo "building blocks" – galaxies
≈ all stars in galaxies

www: Galaxy Survey: 2dFGRS
zoom in: lumpy
step back: smooth

more quantitatively: smooth/"coarse-grain" U at different scales
find rms mass or density fluctuation in sphere of radius R

- clearly, $\delta M/M \gg 1$ over typical gal separation $R \sim 1$ Mpc
- but $\delta M/M \sim 1$ at $R \sim 10$ Mpc
- $\delta M/M < 10^{-4}$ at $R \sim 1000$ Mpc
  $\Rightarrow \delta M/M \rightarrow 0$ for large R

on large scales ($\gg 10$ Mpc) properties same everywhere
U is homogeneous

Now scan around the sky

directional dependence:
on large scales, galaxy distribution looks
(statistically) same in all directions
$\longrightarrow$ on large angular scales, **U is isotropic**

The Universe to Zeroth Order: Cosmological Principle

Observations teach us that

- at any given cosmic time ("epoch")
- to "zeroth order"

the Universe is both:

1. **homogeneous** average properties same at all points
e.g., mass density anywhere is same as mass density everywhere!
i.e., $\langle\rho\rangle(\vec{r}) = \rho$ indep of $\vec{r}$!

2 **isotropic** looks same in all directions

"Cosmological Principle"
the universe is homogeneous & isotropic
first guessed(!) by A. Einstein (1917)

- no special points! no center, no edge!
- "principle of mediocrity"? "ultimate democracy?"